The Elasticity and Strength of a Natural Ringwoodite at Transition Zone Pressures

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Introduction: The transition zone of the Earth's mantle is a critical boundary layer, allowing chemical and thermal mixing between the upper and lower mantle through the passage of subducting slabs and rising plumes. These processes are governed by the rheology of the minerals that comprise the transition zone. More generally, yield strength and its pressure dependence are important material properties with a range of scientific and technical applications. Here we report measurements of the yield strength of a transition zone mineral, a natural iron-bearing ringwoodite, $(Mg_{0.75},Fe_{0.25})_2SiO_4$, which was extracted from the Catherwood meteorite.

Methods and Materials: Radial x-ray diffraction experiments were performed using white radiation and a multi-channel solid state detector. The size of the incident x-ray beam was set to 20 x 20 μm using pairs of slits. The diamond cell was positioned such that the x-ray beam passed through both the sample and Be gasket, parallel to and between the two diamond faces. Each diffraction pattern was collected at a fixed Bragg angle of $2\theta = 9.044(3)^o$ for 15-45 minutes. At each loading step of the diamond cell, a series of 5 to 12 diffraction patterns were obtained by rotating the diamond anvil cell about an axis that bisects the diffraction angle, two theta. This causes the angle between the diffracting plane normal and the diamond cell loading axis to vary between the minimum and maximum stress orientations. Four loading steps were done in all, the first two on compression, the third on decompression, and the fourth on recompression.

Results: Compared to other materials that have been examined by the radial diffraction technique, the strain variation observed in ringwoodite is extreme, varying by more than 3% between the minimum and maximum stress axes. The elastically supported differential stress of ringwoodite was determined to be 5.8-10.2 GPa in the pressure range 6.8-27.0 GPa at room temperature. Our results are broadly consistent with measurements of yield strength on other high-pressure silicates. Available data on yield strength from radial diffraction studies of silicates, metals, oxides, halides, and solid inert gases were also systematically evaluated. At pressures up to 30 GPa, the strength of silicates is in the range of 3-7% of the shear modulus, whereas the strength for other classes of solids is typically less than 2% of the shear modulus.

Conclusions: Radial diffraction measurements in the diamond anvil cell show that the yield strength of a natural ringwoodite is ~6-10 GPa at upper mantle pressures.

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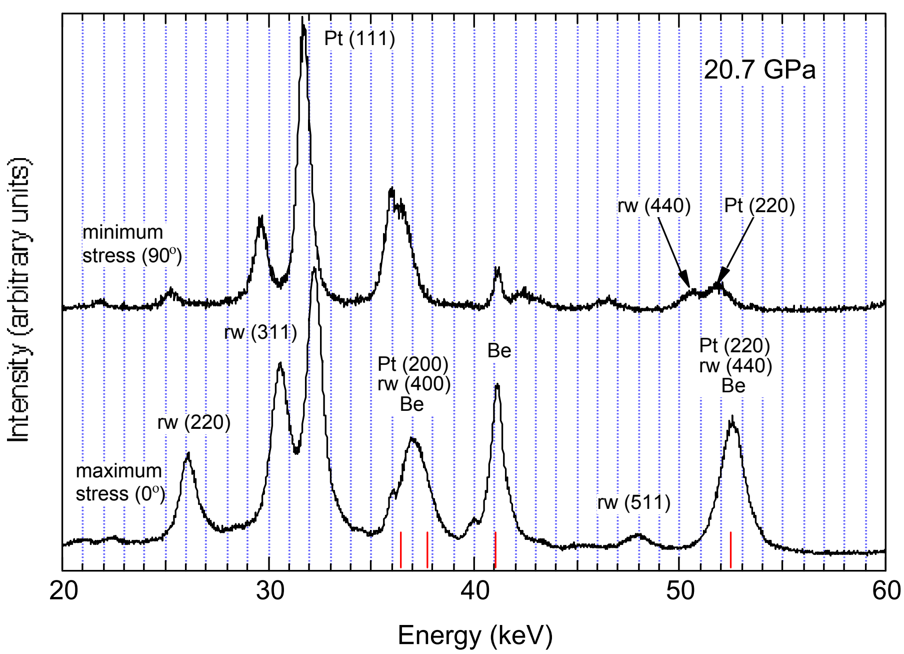

Figure 1. Representative diffraction patterns for ringwoodite at P=20.7 GPa showing the maximum and minimum strain directions. Ringwoodite (rw) and platinum (Pt) reflections are labeled with their (hkl) values. Diffraction line positions arising from the beryllium gasket (Be) are also shown as small vertical lines.